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CANADA'S NON-FERROUS SMELTING/REFINING INDUSTRY

INCO SUDBURY TECHNOLOGICAL PROFILE

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1. INTRODUCTION

This report is one in a series of reports which will attempt to assess the international competitiveness of Canada's non-ferrous smelting industry and recommend strategies for improving the industry's competitive position, while simultaneously providing acceptable methods for reducing SO_2 emissions. The report provides the following information:

- A brief description of Inco Sudbury's present operations, their problems and possible long term solutions.

- A brief description of the proposed modernization alternatives and their advantages and disadvantages. Alternatives are confined to those which appear to be technologically feasible in the short term.

- An outline of the methodology used for comparing the modernization alternatives to the present operations (base case).

- An assessment of the impact of the modernization alternatives on capital and operating costs and smelter/refinery outputs.

- An evaluation of the proposed alternatives compared with longer term higher risk technological alternatives, which are potentially more attractive.

- Recommendations on future R&D initiatives considered essential to the development of these longer term technologies, and to the future viability of the industry.

2. PRESENT OPERATIONS, PROBLEMS & POSSIBLE SOLUTIONS

2.1 Mining/Milling

Present Operations:

Inco has 8 producing mines (essentially all underground) with 6 more on standby and four operating mills, three in the Sudbury area and one at Shebandowan, Ontario. Crushed ore from the mines is processed in three mills (Clarabelle, Frood-Stobie and Shebandowan), which have a combined capacity of about 50,000 mtpd of ore. The mills produce a bulk Ni/Cu concentrate (containing 10 to 20% Ni + Cu) and a pyrrhotite concentrate, containing about 1% Ni. The bulk concentrates from the Clarabelle and Frood-Stobie mills are further processed in the Copper Cliff mill to produce selective Nickel & Copper concentrates which are fed to Inco's nickel & copper smelters. The pyrrhotite concentrate is also sent to Copper Cliff where it is cleaned prior to further processing in Inco's Iron Ore Recovery Plant (IORP), or being pumped to a separate tailings impoundment area. The Shebandowan concentrate is sent directly to the nickel smelter.

The principle nickel and copper bearing minerals in the Sudbury deposits are pentlandite (34% Ni), chalcopyrite (35% Cu) and nickeliferrous pyrrhotite, which contains up to 1% Ni in solid solution. In addition the ores also contain significant quantities of cobalt, gold, silver and platinum group metals (PMs). Recovery of these valuable by-products is very important to the overall economic competitiveness of the Sudbury area ores.

In the beneficiation process the crushed ore is ground to 85% minus 65 mesh and most of the pyrrhotite is removed by magnetic separators. The non-magnetic material which contains the pentlandite and chalcopyrite, most of the gangue-minerals and about 35% of the pyrrhotite (the non-magnetic fraction) is processed in flotation cells to produce a bulk Ni/Cu concentrate and a discard tailings. The bulk Ni/Cu concentrate is then separated into copper and nickel concentrates by flotation with the addition of depressing agents, which allow copper to be selectively floated.

Problems & Possible Solutions:

A typical metallurgical balance for the Inco mills showing grades, and recoveries from the ore and capacity throughputs is shown in Table 1. The figures indicate that while total recovery of copper (93%) is probably as high as can be expected from such a complex ore body, recovery of nickel is dependent on the pyrrhotite content of the ore and on how much of the pyrrhotite is processed for Ni recovery either in the IORP or in the nickel smelter. While it is desirable to recover the nickel in the pyrrhotite it is also desirable to minimize the sulfur to nickel ratio (maximize the nickel content) of the nickel smelter feed, thus minimizing smelter operating costs and SO_2 emissions. Since the nickel in the pyrrhotite is primarily in solid solution and cannot be physically concentrated it is virtually impossible to achieve both of these objectives, without having a separate facility for pyrrhotite processing.

The material balances shown in Table 1 are based on Inco's pre-1983 milling practices, which result in about 50% of the pyrrhotite in the ore going to tailings, about 30% to the IORP and about 20% remaining with the Ni/Cu concentrate going to the nickel smelter. At present there is no market for iron ore pellets; the IORP operation is considered to be uneconomic and is presently operating only to produce acid to fulfill contract obligations. Nickel recovery from the ore is therefore only about 80%, or about 4% lower than when the IORP was also producing nickel. For Inco's typical Sudbury area ores, the maximum possible recovery of nickel, if none of the pyrrhotite is processed for nickel recovery is about 87%. Under these conditions to achieve nickel recoveries of 80% from the ore requires that pentlandite recoveries of about 92% be obtained. From a practical point of view this is an excellent recovery and probably the maximum that can be expected with present flotation technology. It is apparent therefore that to achieve the dual objectives of maximizing nickel recovery from the ore, while also increasing nickel grade and thus reducing costs and SO_2 emissions in the nickel smelter, will require the development of improved technologies such as:

- The development of improved beneficiation techniques for rejecting pyrrhotite from the bulk Ni/Cu concentrate which will minimize nickel and precious metal losses while maximizing nickel grade. A possible target objective of 85% nickel recovery could be considered.

- The development of an economic process for the recovery of nickel and by-products (PM's, sulfur etc.) from pyrrhotite concentrate.

2.2 Nickel Smelting/Refining

Present Operations (Pre 1983)

Inco's Copper Cliff Nickel Smelter [1,2] was built in 1930. Nickel concentrates containing about 10% Ni and 2% Cu are partially roasted with air in multi-hearth roasters and smelted with appropriate fluxing agents, in reverberatory furnaces to produce a 20% to 25% nickel/copper matte and a discard slag. The matte is further oxidized and fluxed to remove iron and sulphur in conventional Pierce Smith converters. Converter slag is recycled to the reverb furnaces. Converter matte, containing about 50% nickel, 26% copper and 0.5% iron, is cast into moulds for slow cooling and separation by grinding, flotation and magnetic separation into a nickel sulfide concentrate (70% Ni, 1% Cu), a copper sulfide concentrate (73% Cu, 5% Ni) and a metallic concentrate (65% Ni, 20% Cu) which also contains most of the precious and platinum group metals in the original concentrate. The copper concentrate is converted to blister copper in the copper smelter, and the copper converter slag, containing residual nickel is recycled to the nickel smelter. The nickel concentrate is roasted with oxygen enriched air in fluid bed roasters to produce nickel oxide for direct sale, or for further refining by a chlorination/hydrogen reduction process to remove and recover copper and produce a 95% nickel alloy. Nickel oxide is also sent to the Port Colborne refinery for reduction smelting with coke for the production of utility nickel, or casting and electrorefining to produce high purity nickel, and copper and cobalt by-products. The Port Colborne operation also includes new facilities for the production of electrorefined cobalt.

The metallics concentrate is processed in the Copper Cliff nickel refinery (built in 1972) to produce high purity nickel pellets and powder and ferro-nickel powder [2,3]. The process involves melting and controlled desulfurizing with oxygen in a top blown rotary converter (TBRC). The molten metallic product is water granulated and fed to a high pressure moderate temperature carbonylation process, where nickel preferentially reacts with carbon monoxide to form nickel carbonyl vapour which is liquified and further purified in a distillation column to remove iron. The nickel carbonyl is then thermally decomposed to form high purity nickel pellets and CO for recycle to the process. Iron in the metallic concentrate which has reacted to form iron carbonyl is recovered as ferro-nickel powder (29% Ni). Copper, residual nickel, cobalt and precious and platinum group metals are recovered from the carbonyl plant residues. The residues are oxygen pressure leached with spent electrolyte to selectively dissolve nickel and cobalt which are precipitated as carbonates for recovery and further refining to nickel and cobalt products. Copper is also recovered by oxygen pressure leaching, followed by purification and electrowinning to produce high purity cathode copper. Precious and platinum group metals, which remain in the leach residues are sent to Port Colborne and overseas for separation and recovery.

A flowsheet of the Copper Cliff Smelter/Refinery complex is shown in Figure 1.

Problems & Possible Solutions:

The major problem areas at the Copper Cliff nickel smelter are related to SO_2 emission control and energy efficiency. About 90% of the total sulphur in the concentrate is removed as SO_2 in the smelter, 50% from the

roaster/reverb and 40% from the converters. Most of the remaining 10% is removed as SO_2 from fluid bed roasting of the high grade nickel sulfide concentrate. With some modifications to the existing circuit, and the development of an efficient method for removing selenium, this latter SO_2 gas stream could be suitable for conversion to sulfuric acid in an acid plant. However the multi-hearth roaster, reverb furnace and converter gas streams are too dilute and/or too variable for efficient capture and conversion in an acid plant.

The smelting process is also energy inefficient and does not take advantage of the sulfur fuel in the concentrate to minimize carbonaceous fuel requirements. This results in higher than desirable operating costs in the smelter.

All of the SO_2 produced in the nickel smelter is presently vented to atmosphere. There is little that can be done economically with the existing smelting process to significantly increase SO_2 capture or improve energy efficiency. Ideally what is required is a new continuous smelting/converting process which can utilize oxygen to minimize fuel requirements and produce a high grade nickel/copper matte and discard slag, while simultaneously producing a high strength SO_2 gas for convertion to acid, liquid SO_2, fertilizer or possibly elemental sulfur. Such a process would probably require pre-roasting for energy balance considerations, and would have to be truly countercurrent to ensure an acceptable discard slag without a separate slag cleaning step.

At present there are no continuous smelting/converting processes for nickel operating on a commercial scale. A number of processes have been proposed in the past and at least one, the WORCRA process (4), has been investigated on a pilot scale. Over the past few years Inco has been investigating, under a government shared cost program, a continuous smelting/converting/slag cleaning process for nickel on a pilot scale at Port Colborne. The process however still requires much more development over a five to ten year time frame to determine technical and economic viability.

Inco's copper flash smelter has also been tested on an experimental basis on nickel concentrates (5). As with copper, the Inco flash smelter using 100% oxygen can operate autogeneously to produce a 25% to 45% Ni/Cu matte and a discard slag. Up to 60% of the sulfur in the concentrate can be removed in a continuous very high concentration ($\simeq$70%) SO_2 gas stream.

Outokumpu flash smelters (2,6) are already used on a commercial scale for processing nickel concentrates. Using oxygen enriched air, matte grades of 45 to 60% can be produced autogeneously with up to 80% of the sulfur in the concentrate being removed as a continuous high strength ($\simeq$10%) SO_2 gas stream. However, because of the high matte grade an electric furnace is required to recover nickel/copper values from the smelter slag prior to discard.

In both the Inco & Outokumpu processes the flash smelter matte must be processed in conventional batch converters to produce the final required matte grade for refining. Although the Inco process is more energy efficient, since no electric furnace is required for slag cleaning, it is not as desirable for SO_2 emission control

because of the lower matte grade which results in about 30 to 40% of the sulfur being removed during batch conversion compared to about 10 to 20% in the Outokumpu process. Ideally what is required is a continuous conversion process to facilitate SO_2 capture from the converting step and thus allow greater flexibility in the smelter operation to maximize recovery of metal values while minimizing energy consumption.

Although Inco's nickel refining processes are well established and do not contribute significantly to existing environmental problems, the overall costs of refining are relatively high. This is primarily because of high operating costs associated with nickel oxide reduction and refining methods, particularly electrorefining. It is desirable therefore to develop more energy efficient and less costly refining techniques for the production of high quality nickel products to meet future anticipated demand and improve competitiveness in world markets. Direct matte leach/electrowinning or matte leach hydrogen reduction processes should receive high priority in the evaluation of possible alternatives.

2.3 Iron Ore Recovery Plant (IORP)

Present Operations (Pre 1983):

Inco's IORP [1,2] for producing nickel, iron ore and sulphuric acid from pyrrhotite was built in 1955. Pyrrhotite contains less than 1% nickel, so that nickel production is only a minor part, (less than 1% by weight) of the total plant output. In the process fluid bed roasters are used to convert most of the sulfides to SO_2 which is recovered in acid plants. The roaster calcine, which is primarily hematite with nickel present as both ferrite and

sulfide, is selectively reduced with natural gas in rotary kilns to convert the nickel to a leachable form, and the hematite to magnetite. The product is then countercurrently leached in ammonia, with CO_2 addition from the reduction kiln off-gases. Magnetic separators are used for solid/liquid separation and the leached magnetite is pelletized and sintered on a travelling grate to produce 67% Fe pellets.

The nickel-bearing solution is treated to recover copper and cobalt, and ammonia is boiled off for recycle to the process. Nickel is precipitated as carbonate and decomposed to produce a reactive nickel oxide. Nickel recovery in the process is about 75 to 80%.

Problems & Possible Solutions:

The main problems with the process have been the inability to obtain adequate markets and netbacks for the acid and iron ore products. Nickel recovery is also not very good, and has led to some marketing problems for the iron ore due to the residual nickel content. What is required for the long term is a process which can efficiently recover the nickel and associated non-ferrous by-products, while also producing higher value sulfur and iron co-products, such as elemental sulfur and sponge iron.

2.4 Copper Smelting/Refining

Present Operations:

The Inco flash smelter [7,8] was first commercialized in 1952, and the present version has been in operation in Sudbury since 1968. Two more Inco flash smelters are presently being built in the USA. In the Inco smelter,

pre-dried concentrate and flux are injected with pure oxygen in a "flash chamber" to produce a 45% to 55% copper matte, a discard slag and a 70% to 80% SO_2 stream which is recovered and sold as liquid SO_2. Because the SO_2 concentrations are so high, gas handling and cleaning costs and SO_2 recovery costs are minimal. The process is also exceptionally energy efficient, requiring essentially no carbonaceous fuel, except for pre-drying the concentrate.

At Inco the flash smelter matte is converted to blister copper by air blowing in conventional batch converters to remove additional sulfur and slag off most of the remaining iron. The blister copper is further refined in anode furnaces to reduce sulfur and oxygen levels, prior to casting into anodes for electrorefining. Converter slag, which contains appreciable copper but also most of the nickel present in the copper concentrate, is recycled to the nickel smelter for both nickel and copper recovery. The batch conversion process results in 45 to 50% of the sulfur in the concentrate being released as a variable concentration variable flow SO_2 gas stream which is cleaned and vented to atmosphere.

In the refinery, well established electrorefining techniques, employing sulphuric acid/copper sulfate electrolyte, are used to produce high purity cathode copper, and to recover precious metals and other byproducts in the form of insoluble slimes, which are further refined to high purity products. Impurity build-up in the electrolyte is controlled by means of a bleed stream which is treated for copper and nickel recovery prior to discard to waste.

Problems & Possible Solutions:

The major problem with Inco's copper smelter is related to SO_2 capture from the copper converters, and to a lesser extent from the flash furnace, where SO_2 capture is limited by the capacity of the liquid SO_2 plant and available markets for the product. Converter gases are not readily amenable to recovery in an acid plant because of the variable SO_2 concentration and gas flow, and the difficulty in maintaining tight fitting converter hoods. The latter is accentuated because of the nickel present in the copper concentrate. Recovery of the nickel from the converter slag requires washing of the converters with nickel matte, which complicates the converter operation, and makes hooding and gas collection difficult and costly. What is needed is a continuous conversion process to facilitate SO_2 capture from the converting step, while minimizing the problems associated with recovering nickel from the converter slag.

Although Inco's copper refining operations are based on conventional well proven techniques, the technology used is old and operating costs are relatively high. It is desirable therefore to develop less costly methods for electrorefining of copper, with particular emphasis on more labour efficient systems which are amenable to continuous operation with minimum recycle of anode copper.

3. PROPOSED MODERNIZATION ALTERNATIVES

Although a number of possible modernization alternatives have been suggested in the preceeding section, only a few have reached an adequate state of development to consider implementation in the short term. The following proposed alternatives are deemed to be the most practical for short term implementation, while maintaining a

reasonable compromise between maximizing environmental benefit and productivity and minimizing cost and technological risk. The alternatives and subsequent metallurgical balances are based on information obtained from Inco literature [including the Hatch Report [9]], from the Ontario/Canada Task Force Report, [10] from SNC Reports [11,12,13], and from discussions with Inco personnel.

3.1 Mill Modernization Alternatives

Inco has developed a new flotation process for increasing the efficiency of pyrrhotite separation from the bulk Ni/Cu concentrate. This process, which incorporates new regrind, flotation and control equipment, has now been installed at a cost of $15 million. Although not yet proven commercially, testwork has indicated that total pyrrhotite rejection from the ore can be increased to 90% from 80%. This will result in an increase in the nickel content of the nickel concentrate to about 14% from 11% and will result in an overall reduction in SO_2 emissions from the smelter by about 20% per unit of nickel produced. It will also result in a reduction in smelter operating costs because of the higher nickel output per unit of throughput, and also because nickel-copper separation efficiency is improved. For these reasons Inco is committed to the new pyrrhotite rejection (PR) process. Although nickel recoveries will be lower, the overall advantages should more than off-set the disadvantages of having to mine and process more ore to achieve the same nickel production. The capital cost of the pyrrhotite rejection process is also very low compared to alternate methods for reducing SO_2 emissions from the nickel smelter.

The PR process therefore is a very desirable modernization alternative, and offers a great deal of potential for further improvement, as operating techniques are developed to maximize nickel grade and minimize nickel and PM losses. Any increase in operating costs in the mill will be small compared to the decrease in operating costs in the smelter resulting from the higher nickel and lower sulfur outputs.

3.2 Nickel Smelter Modernization Alternatives

Based on the knowledge and experience gained in electric furnace smelting at Inco's Thompson, Manitoba smelter, [2,14,15] Inco has developed and tested on a large scale a new fluid bed roast/electric reduction smelt (RRS) process which is capable of removing up to 80% of the total sulfur in the concentrate in a high strength ($\approx$ 10%) SO_2 gas stream from the fluid bed roasters. The electric furnace is operated under reducing conditions to produce a high grade (about 50%) nickel/copper matte and a discard slag. Conventional batch converting is then used to produce a final matte grade of 75% to 80%. Converter slag is recycled to the electric furnace. Recovery of nickel and cobalt in the process is said to be better than with the present process. The process has the potential to efficiently recover 80% of the total sulphur as acid, while limiting SO_2 emissions to about 10% of the sulphur. The latter is divided equally between electric furnace gases and converter gases which are too dilute and too variable respectively for efficient conversion to acid.

A flowsheet of the RRS process is shown in Figure 2.

In general the roast reduction smelt (RRS) process facilitates the recovery of 80% of the sulphur in the concentrate in a high strength SO_2 gas suitable for

conversion to acid. The process however is energy intensive compared to flash smelting processes, in that it does not make efficient use of the sulphur fuel in the concentrate to minimize total energy requirements. Nevertheless the new Inco process has the potential to limit SO_2 emissions to 10% or less of the total sulphur in the concentrate while facilitating the recovery of 80% of the sulphur as acid from the roaster off-gases. In addition it may be possible to recover most of the sulphur in the final Ni/Cu matte (about 10% of total S) in the refining process, either as elemental sulphur if a matte leach process, such as that at Kristiansand Norway [16] is commercially applied, or as acid if the existing matte separation process followed by fluid bed roasting to nickel oxide is used. Since most of the energy used in the smelting process is electrical, with very little requirement for high cost carbonaceous fuels, the new Inco process may be a reasonable compromise between environmental and energy considerations. It also appears to be the only process alternative that has reached an adequate state of development on typical Sudbury concentrates to consider implementation in the short term.

Two versions of the RRS process have been documented to compare with the base case data. The first version (called RRS) considers the erection of a complete new plant on a site at the east end of the existing smelter and assumes that the IORP will not operate. The second version (called RRS/IOP)* also assumes that the IORP will not operate but the roasters and acid plants will be used in the RRS

* Acronym from Ontario/Canada Task Force Report on Inco & Falconbridge (10)

process. However the new smelter, consisting of the electric furnace and converters will still be located at the east end of the existing smelter and calcine from the roasters will have to be transported to the new smelter site.

Both versions assume that the final product from the RRS process will be high grade matte, and that Inco's present refining facilities and technologies will continue to be utilized to produce final saleable products.

3.3 IORP Modernization Alternatives

There appears to be no economic incentive at this time for Inco to process pyrrhotite, particularly if the process economics are based on marketing sulfuric acid and iron ore pellets. In the long term however processing of the pyrrhotite could be attractive, and efforts should be made to segregate as much as possible of the pyrrhotite tailings from main mill tailings to facilitate future recovery of the metal and sulfur values, preferably using a process which produces elemental sulfur. This is discussed further in section 7 of this report.

3.4 Copper Smelter Modernization Alternatives

Although SO_2 capture from the copper converters is desirable, and can theoretically be achieved by appropriate hooding and gas collection systems leading to an acid plant, there is considerable doubt that efficient SO_2 capture can be maintained because of the problems associated with recovering nickel from the converter slag. In addition acid plant operating costs will be high because of the low concentration and variable nature of the gas. Since the IORP acid plants are too far away to use for the fixation of

copper converter SO_2 gas, a separate acid plant near the copper smelter is required. There are therefore no economic incentives to implement this copper circuit modifications (CCM) option. However since there are presently no other short term alternatives for reducing SO_2 emissions from the copper smelter the CCM option has been included in the assessment of modernization alternatives. It is recommended however that high priority be given to the development of a continuous converting process for copper so that a more attractive version of this option can also be considered as a longer term alternative for controlling SO_2 emissions from the copper smelter.

4. METHODOLOGY FOR COMPARISON OF MODERNIZATION ALTERNATIVES

4.1 Mill/Smelter/Refinery Throughputs & Recoveries

The pyrrhotite rejection (PR) process, although not optimized, has already been implemented, and can be considered as part of Inco's present operations. For the base case therefore, for which outputs and cost data are generated, it is assumed that the PR process is fully operational, that the IORP is not operating, and that nickel production is 280 million lb/yr. A mill/smelter metallurgical balance for the base case, with inputs outputs, grades and recoveries is shown in Table 2. As mentioned previously any pyrrhotite separation process will always result in lower overall recoveries of nickel in the bulk Ni/Cu concentrate. The Inco pyrrhotite rejection (PR) process also results in some loss of precious metals. For the base case data in Table 2, these losses have been estimated at 2% each for Ni, Pt group metals and silver. Overall nickel recovery in the concentrates therefore will be in the 78% range. Consequently, for the base case, ore requirements to attain the same nickel production will

increase by about 7.5% over pre 1983 requirements (Table 1), when the IORP was also producing nickel and total nickel recovery in concentrates was 84%.

The figures indicate a mill feed requirement for the base case of about 70% of Inco's mill capacity. Concentrate production therefore is not a constraint to nickel production at Inco for the foreseeable future, even with the lower nickel recoveries resulting from the pyrrhotite rejection process and the closing of the IORP.

To compare the smelter modernization alternatives to the base case, metallurgical balances showing inputs, outputs and recoveries through smelting/refining for both nickel and copper smelters are summarized in Tables 3 and 4. To simplify the comparison the following assumptions have been made for both the base case (Table 3) and the smelter modernization case (Table 4).

1) The pyrrhotite rejection (PR) process is operational and a nickel concentrate grading at least 14% Ni can be produced with average recovery of 78%.

2) The IORP is not operating. However in the RRS/IOP option the IORP roasters and acid plants are used to produce calcine for the RRS process, and by-product sulfuric acid.

3) Nickel production is 280 million lb/yr. This is the maximum production rate that can be considered from the existing operations (Base Case) without exceeding the present MOE control order for SO_2 emissions.

4) The Shebandowan mill is operating at 2000 stpd (80% of capacity). The ratio of Shebandowan to Copper Cliff concentrate production is assumed to be constant regardless of nickel smelter production or the modernization option utilized.

5) Liquid SO_2 production from the copper smelter is limited by the liquid SO_2 plant capacity, which is assumed to be 100,000 mtpy for the present economic study. Reduction below this maximum level due to market constraints would require the fixation of the SO_2 as sulphuric acid. In this event the CCM acid plant should be made large enough to accomodate the extra gas. This allowance has not been included in the cost estimates.

6) Sulfuric acid production from the RRS process is based on 80% sulfur removal (as SO_2) in the roasters and 95% conversion to saleable H_2SO_4 in the acid plant. In actual fact acid conversion efficiency in the RRS/IOP option will be about 2% lower than in the RRS option because the existing IORP acid plants are only single contact. SO_2 emissions therefore will be about 2% higher, and acid production about 2% lower.

7) SO_2 emissions include all forms of sulfur not captured as liquid SO_2 or concentrated H_2SO_4. These include sulfur in slags ($\approx$ 1% of total S), neutralized weak acid from acid plant scrubbers, and SO_2 from the fluid bed roasters in the matte processing plant. Most of the latter ($\approx$ 10% of total S) could possibly be converted to acid if the copper circuit modifications (CCM) option is implemented and an appropriate gas collection system is installed to pipe the SO_2 gas to the new copper smelter acid plant. The latter will

also require that the present operation of the fluid bed roasters be modified, and an appropriate treatment method is developed to remove selenium from the gas stream.

8) Nickel recovery is 2% higher (98 vs 96%) in the RRS process than in the existing smelter (base case). This results in a decrease in ore requirements for the modernized smelter of about 2% over the base case, but still about 5.5% higher than pre 1983 operations, with the IORP operating.

9) Cobalt recovery in the RRS process is 28% higher than in the existing smelter (73% vs 45%). Copper recovery however is 2% lower (94 vs 96%).

10) Recoveries of platinum group metals, gold and silver are assumed to be the same for both base case and RRS process.

11) Metal recoveries in Table 4 will remain valid for all smelter modernization options, with throughputs being directly proportional to smelter nickel production. However sulfuric acid production and SO_2 emission from the copper smelter will obviously change if the CCM option is implemented. These figures are shown in the product breakdown table (Table 5) for 280 and 300 million lb/yr of nickel.

12) For the purpose of calculating revenues a more detailed product breakdown for the base case and modernization options is shown in Table 5 for 280 and 300 million lb/yr Ni. This breakdown is based on average figures estimated by Inco. Saleable cobalt is assumed to be 70% of recovered cobalt, with the remainder being lost

as an impurity in the nickel products. The product breakdown does not include gold since no recovery figures are available, and gold is assumed to be included with the Platinum group metals.

4.2 Capital and Operating Costs

Capital costs for the smelter modernization alternatives, (broken down to the extent possible) are shown in Tables 6 and 7 for 280 and 300 million lb/yr nickel respectively. Costs for the RRS/IOP option are based primarily on the Hatch report.(9) Roaster and acid plant costs for the RRS greenfield option and the CCM option were derived from other sources, (17,18) from the SNC data, (13) and from Inco data. Appropriate inflation factors were used to convert costs to Dec. 31, 1982 Canadian dollars, and accepted factorizing techniques were used to calculate costs at the two levels of nickel production. Capital charges for the CCM option are based on base case copper production figures. Costs therefore are slightly higher than they would be if based on the RRS process copper outputs, which are about 2% lower (Table 5). The difference however is well within the accuracy of the estimates and the costs can be aggregated with the RRS process totals for considering the economics of the combined modernization options.

A breakdown of the incremental operating costs for the modernization options over the pre 1983 smelter operations is shown in Tables 8 and 9 for 280 and 300 million lb/yr nickel respectively. Incremental mining, milling and refining costs are also shown but without any breakdown. Pyrrhotite rejection process operating costs are not included because they are not known at this time.

Incremental costs do not include corporate overhead, interest charges or depreciation. Replacement capital charges for the modernization alternatives are included under materials and supplies in the operating cost tables.

Nickel smelter operating costs for the base case and RRS are based primarily on the Hatch report.[9] Labour, power and maintenance costs are slightly lower in the roaster section for the RRS option than for the RRS/IOP because a calcine transportation system is not required.

Copper smelter operating costs were derived from in-house data and other sources, [7,19] and from discussions with Inco. Costs for the CCM option were derived from the SNC reports [11,12,13] using unit costs quoted in the Hatch report.[9]

Mining, milling and refining costs were based primarily on in-house and published data [20,21], and from discussions with Inco personnel. Nickel refining costs include all costs to convert matte to saleable nickel products.

5. IMPACTS OF MODERNIZATION

5.1 Capital Costs

Based on the capital cost estimates in Tables 6 and 7, a minimum of $C430 million will be required to implement the RRS/IOP option. A greenfield RRS plant would require at least $176 million additional capital.

Capital costs of the CCM option for the copper smelter will be about $120 million.

5.2 Operating Costs

Implementation of the RRS process will result in lower mine/mill operating costs by virtue of the lower requirement for concentrate feed to the smelter to give a fixed output of nickel. These savings reflect the 98% nickel smelter recovery claimed for the RRS process compared with 96% for the base case.

Lower operating costs will also be obtained in the nickel smelter, primarily because of lower labour costs in the smelter and steam credits from the roasters, which more than off-set the roaster and acid plant costs and higher energy costs of the RRS process.

Based on the operating costs documented in Tables 8 and 9, the maximum operating cost savings that could be achieved by implementing the RRS process are about $C22 million/yr for 280 to 300 million lb/yr nickel. Operating cost savings for the RRS/IOP option are about $2 million/year less than this.

About 50 to 55% of the operating cost savings is the result of lower mining/milling costs resulting from lower ore requirements (higher nickel recovery). Most of the remainder is due to lower labour costs in the nickel smelter.

Implementation of the CCM option will increase operating costs in the copper smelter by about $C4.5 million/yr.

5.3 Revenues

The effect of implementing the modernization options on incremental outputs and revenues is shown in Table 10. Although the RRS process achieves significant increases in nickel and cobalt recovery, (versus the base case) there is virtually no increase in metal revenues shown in Table 10. This is primarily because the assessment of the modernization options is based on constant nickel output, rather than constant ore or concentrate input to the process. The net effect, as already noted in the operating cost comparisons, is a reduction in ore and concentrate requirements per pound of nickel produced, which reduces the outputs of by-product metals and the revenues therefrom. For the two levels of nickel production shown, the decrease in by-product revenues (copper, PM's and silver) is approximately off-set by the increase in cobalt credits resulting from increased cobalt recovery. This essentially implies that any incremental revenues attributable to the RRS process will be dependent upon netbacks from sulfuric acid sales. At a netback of $US16/tonne, acid revenues are estimated at approximately $US11 million/yr, increasing to about $16 million/yr if the CCM option is also implemented. These revenues could decrease to minus $10 to $15 million/yr at acid netbacks of -$US12/tonne (see Table 10).

Prices used for metal and acid revenues in Table 10 are based on EMR and DRIE (ITC) commodity forecasts for the 1990's. All prices are in 1982 US dollars. For cobalt, PM's and silver, prices used also reflect deductions for refining charges of 44%, 5% and 5% respectively.

5.4 SO_2 Emissions

Based on the sulfur balances in Tables 3, 4 and 5, implementation of the RRS process technology will result in a decrease in SO_2 emissions of about 59% over the base case. Capture of SO_2 from the copper converters via the CCM option would result in a further decrease of 23%, bringing total capture of SO_2 to about 82% of the sulfur normally entering the nickel/copper smelters under the base case conditions.

5.5 Summary of Incremental Impacts of Modernization

A summary of the product outputs, SO_2 emissions, capital costs, incremental revenues and operating costs, and total incremental savings in $US/yr for the modernization alternatives is shown in Table 11. These figures can be used directly to determine the relative profitability of the modernization options versus the pre 1983 operations for nickel throughputs of 280 and 300 million/lb/yr.

For the RRS/IOP option, the maximum incremental benefits for the above nickel throughputs is estimated to be in the range $US26 to $US27 million/yr. Approximately 59% of this is operating cost savings, with the remainder coming from sulfuric acid sales.

For the CCM option, operating costs are about equal to estimated acid revenues, leaving nothing to pay for the $120 million capital required.

It is worth noting here that the total incremental benefits for the RRS/IOP ($US million/yr) are considerably less than the $C51.8 million ($\approx$ $US41.5 million) estimated in the Hatch report [9] for 300 million lb/yr nickel.

This differential cannot be accounted for by differences in smelter operating costs or in the metal prices used in the comparison. There are however a number of valid differences in the methodology for comparing the RRS to the base case. The major differences are as follows:

Basis for Comparison
Base Case Versus RRS/IOP

	CANMET	HATCH
1.	Comparison based on constant nickel output from processes. Costs include mining/milling and refining.	Comparison based on constant nickel input to the smelting process. Costs do not include mining, milling or refining.
2.	Cobalt revenues based on saleable cobalt.	Cobalt revenues not corrected for saleable cobalt (70%).
3.	No incremental nickel revenues since comparison is based on constant nickel output.	Incremental nickel revenues based on full value for nickel without correcting for refining costs.
4.	RRS by-product credits are reduced because of lower ore requirements.	By-product credits not affected, since inputs are constant.
5.	Incremental benefits dependent primarily on mining/milling cost savings.	Incremental benefits dependent primarily on incremental nickel revenues.
6.	RRS process nickel recovery estimated at 98% from 14% Ni concentrate.	RRS process nickel recovery based on 98.2% recovery from 15% Ni concentrate.

Even after applying corrections to the Hatch revenue estimates for nickel and cobalt, and converting everything to US dollars, there is still a difference of about $US10 million/yr ($US15.67 vs $US25.96 neglecting acid credits). This difference can only be attributed to the methodology used, (constant nickel output versus constant nickel input), with the CANMET incremental benefits primarily dependent on the savings in mining/milling costs, while the Hatch benefits are primarily dependent on incremental nickel revenues. Although neither method would appear to be "more correct" than the other, the Hatch methodology obviously makes the RRS/IOP look more attractive, since incremental benefits (neglecting sulfuric acid revenues) will be about $US10 million ($\approx$ 60%) higher.

6. EVALUATION OF MODERNIZATION ALTERNATIVES

6.1 Mill Modernization

As stated earlier, implementation of the pyrrhotite rejection (PR) process is a very economically attractive method for reducing smelter SO_2 emissions and smelter operating costs. Recent studies at Inco [22] have indicated that much higher levels of pyrrhotite rejection can be achieved, and it may be possible to produce nickel concentrates containing up to 20% nickel. This is a considerably higher grade than used in the present study and would significantly reduce SO_2 emissions and operating costs in the smelting process. In addition copper levels in the nickel concentrate and nickel levels in the copper concentrate can be substantially reduced. This would also have a beneficial effect in minimizing the problems and costs associated with recovering nickel from the copper smelter and vice versa. It is desirable therefore to thoroughly evaluate this improved pyrrhotite rejection

process, to determine the incentives for implementation by accurately comparing the downstream economic and environmental benefits against the increased mining/milling costs, and possibly decreased by-product credits, resulting from decreased recovery of metal values from the ore.

6.2 Nickel Smelter/Refinery

Although the RRS process does provide significant incremental savings over the base case, the savings, even if sulfuric acid revenues are realized, are unlikely to be adequate to justify the $C430 million capital expenditure required. One of the major reasons for this is that smelter operating cost savings are primarily the result of lower labour requirements, and potential energy cost savings are not realized. Although this report, which is based on the Hatch report, shows an energy credit to the RRS process of about $C2.9 million/yr, energy costs in the RRS are actually higher than they were in Inco's pre 1983 operations with the IORP operating. Using this comparison would eliminate the steam credits ($C5.9M) from the RRS, and the stack gas heating costs ($2.7M) from the base case figures, resulting in a total energy cost deficit for the RRS of about $C5.7M/yr.

It is obvious therefore that the RRS process is not an ideal modernization option for the nickel smelter. To maximize operating cost savings a process is required which can operate continuously, produce a high strength SO_2 gas and effectively utilize the sulfur fuel in the concentrate to minimize energy requirements. The combination of an Inco flash smelter with a continuous converting process for nickel could meet these requirements. However, the process

would be less amenable to utilization of existing equipment (roasters, acid plants converters). Capital costs therefore could be higher than the RRS/IOP option.

Regardless of the modernization technology adopted for the nickel smelter, the capital costs are likely to be in the same range as those estimated for the RRS/IOP and RRS options, unless significant reductions can be achieved by utilizing existing equipment. It will therefore always be difficult to justify the capital costs based on smelter operating cost savings alone, particularly since total nickel smelter operating costs only account for about 12% of the total yearly operating costs of the Inco Sudbury Complex. It is important therefore to consider the nickel smelter modernization as only part of a total modernization concept, which would include the development of other, less capital intensive technologies, designed to reduce mining, milling and refining costs, as well as having a potentially beneficial effect on smelting costs (such as the PR process). In this way the costs of SO_2 control do not have to be borne solely by the nickel smelter.

6.3 Copper Smelter/Refinery

There are no economic incentives to implement the CCM option to capture SO_2 from the copper smelter. At best the acid plant operating costs may be covered by sulfuric acid revenues. To significantly decrease operating costs in the copper smelter, while facilitating SO_2 capture requires the development of a continuous converting process, to convert Inco flash furnace matte to acceptable quality blister copper. Such a process could eliminate most of the present converter aisle, reduce labour and energy costs and fugitive emissions, and produce a continuous high strength SO_2 gas readily amenable to capture in an acid plant.

7. RECOMMENDED R&D INITIATIVES

7.1 Mining

Mining costs constitute the largest single component (at least 45%) of the total operating costs of the Sudbury Complex. Although a detailed discussion of mining technologies is beyond the scope of this report, it is obvious that improvements in mining techniques which result in lower mining costs will have a very significant effect on the total costs for producing nickel and copper from Sudbury ores. It is recommended therefore that research into the development of lower cost mining methods be given a high priority in future R&D efforts to improve the competitiveness of Inco Sudbury operations.

7.2 Milling

The downstream economic and environmental benefits of implementing an improved pyrrhotite rejection process have already been mentioned. To maximize these benefits, a comprehensive R&D program is required, incorporating both fundamental and pilot scale studies, to develop beneficiation techniques which will minimize metal losses during pyrrhotite rejection while producing high grade nickel and copper concentrates, and efficient nickel/copper separation.

7.3 Nickel Smelting

There is little doubt that the RRS process offers the best short term compromise between minimizing technological risk and maximizing environmental benefit. Economic benefits however are marginal at best. Based on the previous studies carried out by Inco, and on the

commercially proven Outokumpu flash smelter technology, a flash smelting/continuous converting process for nickel appears to offer the best potential for maximizing both economic and environmental benefits. It is recommended therefore that a comprehensive R&D program be initiated to determine the technical feasibility of such a process, with special emphasis on obtaining high metal recoveries while minimizing energy requirements and costs for slag cleaning. The latter could include the use of rejected pyrrhotite to facilitate the production of a discard slag. Cost benefits however would have to be weighed carefully against increased SO_2 emissions resulting from the use of pyrrhotite.

As part of the R&D program there is also a great incentive to determine the feasibility of utilizing existing equipment to reduce the capital costs of both the RRS and the flash smelting/continuous converting processes.

7.4 Nickel Refining

Nickel refining costs amount to about 21% of total costs for the Inco Sudbury complex and are considerably higher than nickel smelting costs. There is therefore considerable incentive to develop less costly refining methods for nickel, particularly for the nickel sulfide from the matte separation process. The present roast, carbon reduction/electrorefine process is relatively costly and the roast, chlorine upgrading/hydrogen reduction process does not recover by-product cobalt. It is recommended therefore that alternate technologies (such as a matte leach electrowin process) be investigated for recovering nickel, cobalt and other by-products (including sulfur) directly from the nickel sulfide matte.

7.5 Copper Smelting

As already stated a continuous converting process for copper is by far the most promising alternative for Inco to maximize economic and environmental benefits in the copper smelter. It is recommended therefore that a comprehensive R&D program be initiated to determine the technical feasibility of a flash smelting/continuous converting process for copper, with emphasis on maximizing copper recovery while minimizing costs associated with slag cleaning, including by-product nickel recovery.

In addition it is recommended that research be undertaken to develop new acid plant technologies, employing fluid bed catalytic converters, to facilitate the conversion of high strength (> 25%) SO_2 gases, and if desirable recover by-product steam credits. This would allow full advantage to be taken of the high strength flash furnace gases and would minimize the cost of acid production. The technology can of course also be applied to a nickel flash smelting/continuous converting process.

7.6 Copper Refining

As with nickel, Inco's copper refinery is old and relatively expensive. Copper refining costs are at least as high as copper smelting costs. There is incentive therefore to investigate improved refining techniques, particularly those that could substantially reduce labour, inventory and anode recycle costs. It is recommended therefore that R&D be initiated to investigate improved electrorefining techniques, with particular emphasis on the above mentioned elements.

7.7 Pyrrhotite Processing

For the long term it is desirable to develop a process for treating pyrrhotite, particularly with the introduction of the pyrrhotite rejection process and the possible extended use of it. A comprehensive R&D program is therefore recommended, to develop a process which has the capability to recover nickel and associated valuable metals from pyrrhotite, while converting sulfides directly to elemental sulfur. A process employing "chloride metallurgy", either aqueous or dry, is recommended as the most promising approach for a technically and economically viable process.

8. ACKNOWLEDGEMENTS

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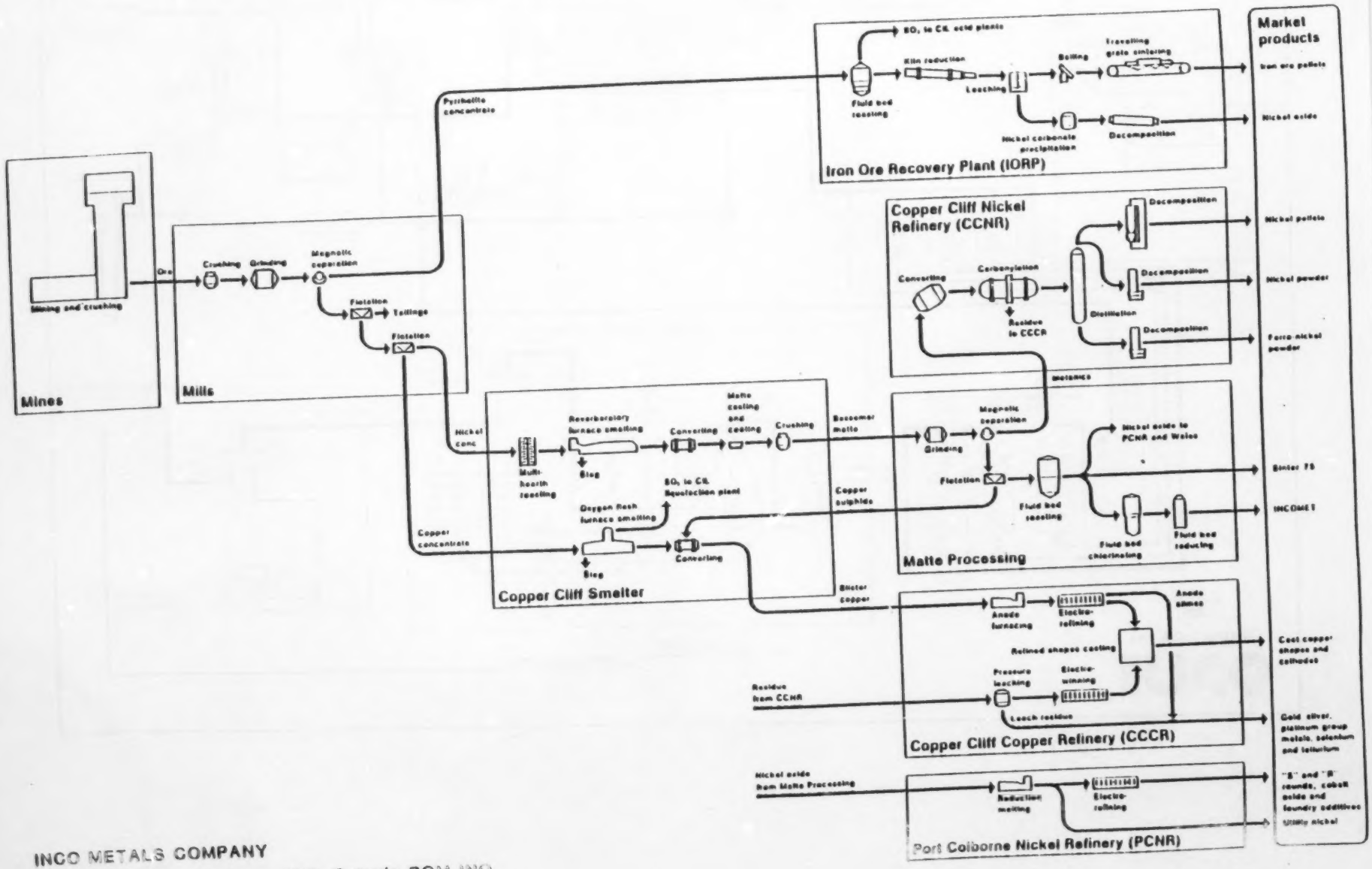
FIGURE 1

SUDBURY OPERATIONS FLOWSHEET (1979)



INCO METALS COMPANY
Ontario Division - Copper Cliff, Ontario POM 1NO

Figure 2

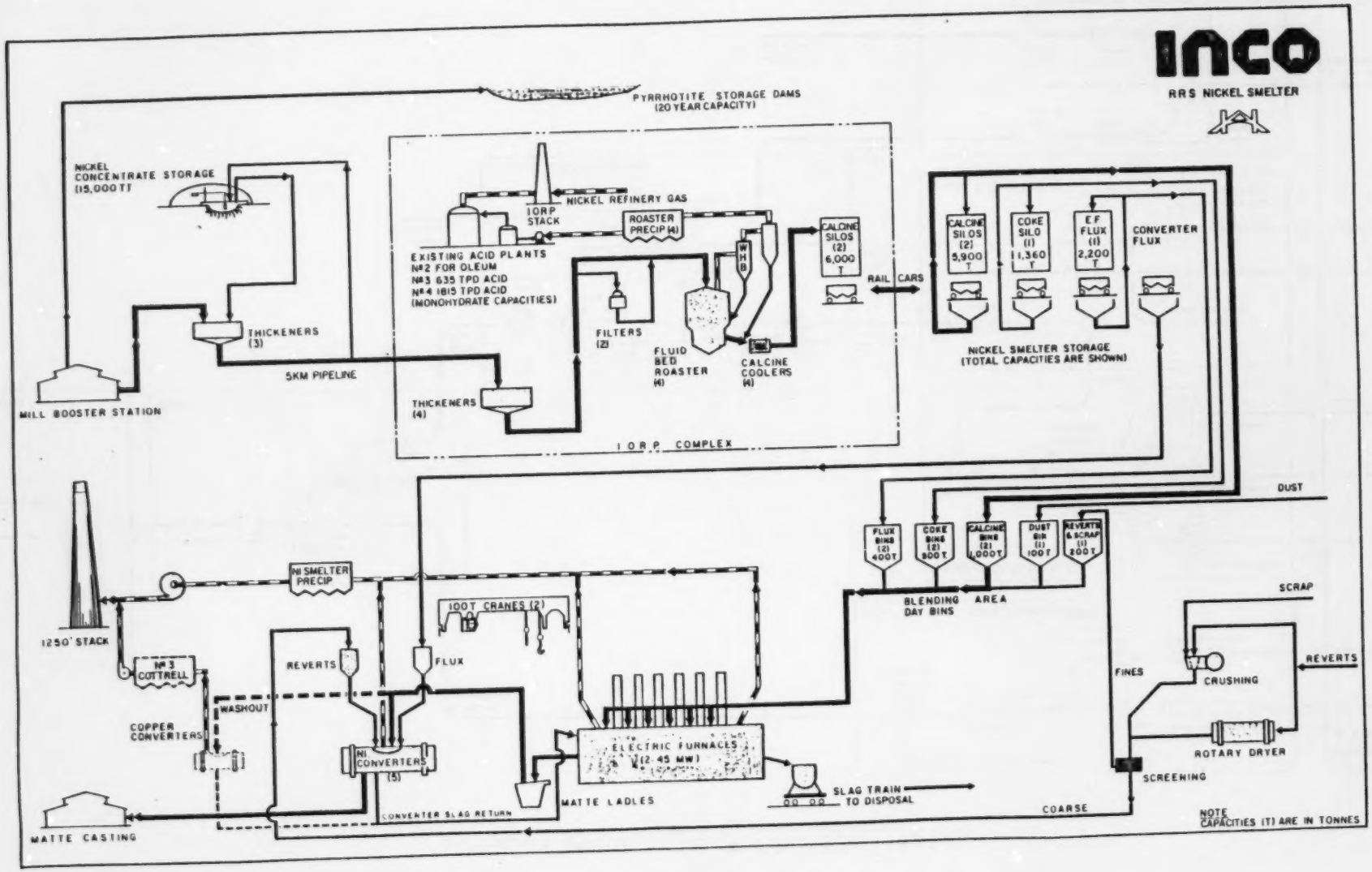

INCO
RRS NICKEL SMELTER
PYRRHOTITE STORAGE DAMS
(20 YEAR CAPACITY)
NICKEL CONCENTRATE STORAGE (15,000 T)
THICKENERS (3)
5KM PIPELINE
MILL BOOSTER STATION
EXISTING ACID PLANTS
№2 FOR OLEUM
№3 635 TPD ACID
№4 1815 TPD ACID
(MONOHYDRATE CAPACITIES)
IORP STACK
NICKEL REFINERY GAS
ROASTER PRECIP (4)
FILTERS (2)
FLUID BED ROASTER (4)
WHB
CALCINE COOLERS (4)
CALCINE SILOS (2) 6,000 T
THICKENERS (4)
IORP COMPLEX
RAIL CARS
CALCINE SILOS (2) 5,900 T
COKE SILO (1) 1,360 T
EF FLUX (1) 2,200 T
CONVERTER FLUX
NICKEL SMELTER STORAGE (TOTAL CAPACITIES ARE SHOWN)
DUST
FLUX BINS (2) 400T
COKE BINS (2) 300T
CALCINE BINS (2) 1,000T
DUST BIN (1) 100T
REVERTS & SCRAP (1) 200T
BLENDING DAY BINS
AREA
SCRAP
REVERTS
FINES
CRUSHING
ROTARY DRYER
SCREENING
COARSE
NOTE
CAPACITIES (T) ARE IN TONNES
Ni SMELTER PRECIP
1250' STACK
№3 COTTRELL
COPPER CONVERTERS
WASHOUT
REVERTS
FLUX
100T CRANES (2)
Ni CONVERTERS (5)
ELECTRIC FURNACES (12-45 MW)
MATTE LADLES
CONVERTER SLAG RETURN
SLAG TRAIN TO DISPOSAL
MATTE CASTING

TABLE 1
INCO SUDBURY
MILL CAPACITY GRADES & RECOVERIES
(Pre 1983)

		ORE	CONCENTRATES				
			Bulk Ni/Cu	SELECTIVE		Clean Po to IORP	Po to tailings
				Ni	Cu		
Mill Capacity*	(1000) mtpy	17,000	2,270	1,700	570	970	1,600
	(1000) Ni (lb/yr) Cu	525,000 485,000	420,000 450,000	405,000 77,000	15,000 373,000	21,000 2,400	26,000 3,900
	Co	19,000	14,000	14,000			-
	(1000) PM's (oz/yr) Ag	800 3,400	560 2,500	560 2,500			
Ore & Conc. Grades	% Ni	1.4	8.5	11	1.2	1	0.7
	% Cu	1.3	9	2.0	30	0.1	0.1
	% Co	Q.05	0.3				
	PM's oz/mt Ag oz/mt	0.045 0.2	0.25 1				
% Recovery from Ore	Ni	-	80	77	3	4	5
	Cu	-	93	16	77	0.5	0.8
	Co	-	75	75			
	PM's	-	70	70		-	-
	Ag	-	73	73		-	-

* Broken down as follows:

Clarabelle	35,000 stpd.
Frood Stobie	18,000 stpd.
Shebandowan	2,500 stpd.
Total	**55,500 stpd.**

TABLE 2
INCO SUDBURY MILL/SMELTER/REFINERY/THROUGHPUTS GRADES & RECOVERIES
BASE CASE
(280 million lb/yr Ni)

ORE MILLED	MILL CONCENTRATES				THROUGHPUTS	SMELTER/REFINERY		
	Po to storage	Bulk * Ni/Cu	SELECTIVE Ni	SELECTIVE Cu		Metal Products	Sulfur Products (1000 mtpy) Liquid SO_2	Sulfur Products (1000 mtpy) SO_2 Emissions
					(1000 mtpy)			
12,100	2,100	1,350	910	440				
1,200	735	430	280	150	Total S		100	760
374,000	42,000	292,000	280,000	12,000	(1000 lb/yr)			
345,000	4,700	320,000	30,000	290,000	Ni	280,000		
13,400		10,000	10,000		Cu	310,000		
					Co	4,500		
545		370	370		(1000 oz/yr) PM	352		
2,430		1,725	1,725		Ag	1,640		
					GRADES			
10	35	32	31	34	% S			
1.4	0.9	10	14	1.2	% Ni			
1.3	0.1	11	1.5	30	% Cu			
0.05		0.4			% Co			
0.045		0.3			(oz/mt) PM			
0.2		1.3			(oz/mt) Ag			
	% Recovery from Ore				% RECOVERY	% Recovery from Conc.		
	61	36	23	13	S	-	12	88
	11	78	75	3	Ni	96		
	1.3	93	9	84	Cu	97		
		75	75		Co	45		
		68	68		PM	95		
		71	71		Ag	95		

* After Po Rejection.

TABLE 3
INCO SUDBURY SMELTER/REFINERY THROUGHPUTS & RECOVERIES
BASE CASE
(280 million lb/yr Ni)

INPUTS					MATERIAL FLOWS	OUTPUTS		
ORE MILLED	CONCENTRATES			TOTAL IN CONC's		Ni Smelter	Cu Smelter	Total Outputs
	Shebandowan	C.C. Nickel	C.C. Copper					
12,100	180	815	420	1,415	**(1000 mtpy)** **Total**	-	-	-
1,200	40	252	143	435	**S**	-	-	-
-	-	-	-	-	**liq. SO_2**	-	100	100
-	-	-	-	-	**H_2SO_4**	0	0	0
-	-	-	-	-	**SO_2 emissions**	570	200	770
374,000	30,000	251,000	11,000	292,000	**(1000 lb/yr)** **Ni**	280,000		280,000
345,000	15,000	28,000	277,000	320,000	**Cu**	19,000	291,000	310,000
13,400	500	9,500		10,000	**Co**	4,500		4,500
545	-	370		370	**(1000 oz/yr)** **PM**	352		352
2,430	100	1,625		1,725	**Ag**	1,640		1,640
	% Recovery from Ore				**RECOVERIES**	% Recovery from Concentrate		% Recovery from Ore
	3	21	12	36	**S (emissions)**	65.5	23.5	32
	8	67	3	78	**S (Fixed)**	0	12	4
	4	8	81	93	**Ni**	96		75
	4	71		75	**Cu**	96	98.5	90
	-	68		68	**Co**	45		34
	4	67		71	**PM**	95		65
					Ag	95		67

TABLE 4
INCO SUDBURY SMELTER/REFINERY THROUGHPUTS & RECOVERIES
RRS PROCESS
(280 million lb/yr Ni)

INPUTS					MATERIAL FLOWS	OUTPUTS		
ORE MILLED	CONCENTRATES			TOTAL IN CONC's		Ni Smelter	Cu Smelter	Total Outputs
	Shebandowan	C.C. Nickel	C.C. Copper					
11,900	176	798	411	1,385	**(1000 mtpy)** **Total**			
1,190	39	247	140	426	S			
					liq. SO_2	-	100	100
					H_2SO_4	665	0	665
					SO_2 emissions	126	192	318
366,000	29,000	246,000	11,000	286,000	**(1000 lb/yr)** **Ni**	280,000		280,000
340,000	14,000	27,000	275,000	316,000	**Cu**	19,000	284,000	303,000
13,800	450	9,300		9,750	**Co**	7,100		7,100
535	-	364		364	**(1000 oz/yr)** **PM**	346		346
2,380	100	1,590		1,690	**Ag**	1,600		1,600
	% Recovery from Ore				**RECOVERIES**	% Recovery from Concentrate		% Recovery from Ore
	3	21	12	36	**S (emissions)**	15	22	13.5
	8	67	3	78	**S (Fixed)**	51	12	22.5
	4	8	81	93	**Ni**	98	-	76.5
	4	71		75	**Cu**	94	98.5	89.5
	-	68		68	**Co**	73		55
	4	67		71	**PM**	95		65
					Ag	95		67

TABLE 5
INCO SUDBURY

PRODUCT BREAKDOWNS FOR BASE CASE AND RRS PROCESS AT TWO LEVELS OF NICKEL OUTPUT

PRODUCTS	ANNUAL OUTPUTS			
	280 x 10^6 lbs/y Ni		300 x 10^6 lbs/y Ni	
	Base Case	RRS	Base Case*	RRS
Nickel Products (10^6 lbs/yr Ni Content)				
Class 1 Nickel - Ni Pellets	75	75	80	80
- Ni Powder	13	13	14	14
Ni Pellets (Clydach)	64	64	69	69
- Electro Nickel (PCNR)	58	58	62	62
Total Class 1 Nickel	210	210	225	225
Class 2 Nickel - Sinter 75	23	23	25	25
- Incomet	24	24	26	26
- Incomet Granules	23	23	25	25
Total Class 2 Nickel	70	70	75	75
Total Nickel Products	280	280	300	300
Copper Products (10^6 lbs/yr Cu Content)				
Electrorefined Cathodes	291	284	311	304
Electrowon Cathodes	19	19	21	21
Total Copper Products	310	303	332	324
Cobalt Products (10^3 lbs/yr Co Content)				
Cobalt Metal	2,150	3,970	2,375	4,325
Cobalt Oxide (Ceramic Grade)	1,000	1,000	1,000	1,000
Total Cobalt Output	3,150	4,970	3,375	5,325
Platinum Group Metals (10^3 ozs/y PM's)				
In Miscellaneous PM - bearing Materials	352	346	377	371
Gold (10^3 ozs/y Au)				
In Gold - bearing Materials				
Silver (10^3 ozs/y AG)				
In Silver-bearing Materials	1,640	1,600	1,757	1,714
Sulphur-Bearing Products (10^3 tonnes/yr)				
Liquid SO_2	100	100	100	100
Sulphuric Acid (as 100% H_2SO_4) (1)	0	665	0	712
(2)	-	945	-	1010
Gaseous SO_2 Emissions (1)	770	318	825	341
(2)	-	136	-	146

(1) Without CCM option.
(2) With CCM option.
* Hypothetical base case for comparison purposes only.

Inco Sudbury Modernization Options

TABLE 6
CAPITAL COSTS

280 x 10^6 lbs Ni/yr.

COST ITEMS	Cdn Dollars x 10^6 (Dec. 31/1982)				
	RRS Option		RRS/IOP Option		CCM Option
Copper Smelter - Ductwork & Hoods for Smelter					77.00
- Acid Plant + auxilliaries (960 mtd H_2SO_4)					42.00
Total					**119.00**
Nickel Smelter - Concentrate Handling	47.90		10.91		
- Roasters (RRS)	63.98		-		
- Modifications to IORP Roasters	-		12.54		
- Smelter Materials Handling	19.15		33.13		
- Nickel Smelter	90.38		90.38		
- Converter Aisle	59.27		59.27		
- Smelter Gas Handling	33.32		33.32		
- Infrastructure	72.10		72.10		
- Acid Plant + auxilliaries (2280 mtd H_2SO_4)	53.16		-		
Total Direct Costs	**439.26**	439.26	**311.65**	311.65	
Engineering & Project Management	59.37		42.13		
Construction Management	15.38		10.91		
	74.75	74.75	**53.04**	53.04	
Temporary Construction Facilities	7.42		5.27		
Spare Parts	4.03		2.87		
Insurance	2.15		1.53		
	13.60	13.60	**9.67**	9.67	
		527.61		374.36	
Contingency 15%		79.14		56.15	
TOTALS		**606.75**		**430.51**	**119.00**

Inco Sudbury Modernization Options

TABLE 7
CAPITAL COSTS

300 x 10^6 lbs Ni/yr.

COST ITEMS	Cdn Dollars x 10^6 (Dec. 31/1982)				
	RRS Option		RRS/IOP Option		CCM Option
Copper Smelter - Ductwork & Hoods for Smelter					77.00
- Acid Plant + auxilliaries (H_2SO_4)					44.00
Total					**121.00**
Nickel Smelter - Concentrate Handling	50.00		11.4		
- Roasters (RRS)	66.67		-		
- Modifications to IORP Roasters	-		13.10		
- Smelter Materials Handling	20.00		34.60		
- Nickel Smelter	94.40		94.40		
- Converter Aisle	61.90		61.90		
- Smelter Gas Handling	34.80		34.80		
- Infrastructure	75.30		75.30		
- Acid Plant + auxilliaries (H_2SO_4)	55.09		-		
Total Direct Costs	**458.16**	458.16	**325.50**	325.50	
Engineering & Project Management	61.94		44.00		
Construction Management	16.04		11.39		
	77.98	77.98	**55.39**	55.39	
Temporary Construction Facilities	7.73		5.50		
Spare Parts	4.21		2.99		
Insurance	2.24		1.59		
	14.18	14.18	**10.08**	10.08	
		550.32		390.97	
Contingency 15%		82.55		58.65	
TOTALS		**632.87**		**449.62**	**121.00**

TABLE 8

INCREMENTAL OPERATING COSTS

Inco Sudbury Modernization Options — **280 x 10^6 lbs/y Ni**

Plant Areas and Cost Components	RRS $C x 10^6/y		RRS/IOP $C x 10^6/y		CCM $C x 10^6/y	
Mining	- 9		- 9			
Milling*	- 2		- 2			
Total Mining/Milling	-11	-11	-11	-11		
Nickel Circuit						
Roasting						
- Labour	+ 4.00		+ 5.02			
- Energy - Gas/Oil	- 0.33		- 0.33			
- Electric	+ 0.38		+ 0.97			
Materials Supplies, - Operating & Maintenance	+ 1.00		+ 1.16			
Sub-Total	+ 5.05		+ 6.82			
Less Steam Credits	(5.48)		(5.48)			
Sub-Total (Roasting)	- 0.43	-0.43	+ 1.34	+1.34		
Nickel Smelting						
- Labour	-13.02		-13.02			
- Energy - Gas/Oil	-18.54		-18.54			
- Electric	+13.11		+13.11			
- Coke	+ 5.75		+ 5.75			
Materials/Supplies, Operating & Maintenance	- 2.08		- 2.08			
Sub-Total (Smelting)	-14.70	-14.70	-14.70	-14.70		
Acid Plant		+ 6.24		+ 6.24		
Total Smelting		- 8.89		- 7.12		
Nickel Refining		0		0		
Total Nickel		- 8.89		- 7.12		
Copper Circuit						
Copper Smelting						
- Labour	- 0.14		- 0.14		+ 0.11	
- Energy - Gas/Oil	- 0.09		- 0.09			
- Electricity	- 0.17		- 0.17		+ 0.30	
Materials/Supplies, Operating & Maintenance	- 0.24		- 0.24		+ 1.65	
Sub-Total (Smelting)	- 0.64	- 0.64	- 0.64	- 0.64	+ 2.06	+ 2.06
Acid Plant		0		0		+ 2.25
Copper Refining		- 0.70		- 0.70		
Total Copper		- 1.34		- 1.34		+ 4.31
TOTALS (overall)		-21.23		-19.46		

* Excluding costs of Pyrrhotite rejection (PR) Process.

TABLE 9

INCREMENTAL OPERATING COSTS

Inco Sudbury Modernization Options — 300×10^6 lbs/y Ni

Plant Areas and Cost Components	RRS $C x 10^6/y		RRS/IOP $C x 10^6/y		CCM $C x 10^6/y	
Mining	- 9.6		- 9.6			
Milling*	- 2.1		- 2.1			
Total Mining/Milling	-11.7	-11.7	-11.7	-11.7		
Nickel Circuit						
Roasting						
- Labour	+ 4.18		+ 5.24			
- Energy - Gas/Oil	- 0.35		- 0.35			
- Electric	+ 0.41		+ 1.04			
Materials Supplies, - Operating & Maintenance	+ 1.05		+ 1.22			
Sub-Total	+ 5.29		+ 7.15			
Less Steam Credits	(5.87)		(5.87)			
Sub-Total (Roasting)	- 0.58	- 0.58	+ 1.28	+ 1.28		
Nickel Smelting						
- Labour	-13.6		-13.6			
- Energy - Gas/Oil	-19.86		-19.86			
- Electric	+14.14		+14.14			
- Coke	+ 6.16		+ 6.16			
Materials/Supplies, Operating & Maintenance	- 2.18		- 2.18			
Sub-Total (Smelting)	-15.34	-15.34	-15.34	-15.34		
Acid Plant		+ 6.68		+ 6.68		
Total Smelting		- 9.24		- 7.38		
Nickel Refining		0		0		
Total Nickel		- 9.24		- 7.38		
Copper Circuit						
Copper Smelting						
- Labour	- 0.16		- 0.16		+ 0.12	
- Energy - Gas/Oil	- 0.10		- 0.10			
- Electricity	- 0.19		- 0.19		+ 0.32	
Materials/Supplies, Operating & Maintenance	- 0.27		- 0.27		+ 1.72	
Sub-Total (Smelting)	- 0.72	- 0.72	- 0.72	- 0.72	+ 2.16	+ 2.16
Acid Plant		0		0		+ 2.40
Copper Refining		- 0.80		- 0.80		
Total Copper		- 1.52		- 1.52		+ 4.56
TOTALS (overall)		-22.46		-20.6		

* Excluding costs of Pyrrhotite rejection (PR) Process.

TABLE 10

INCO SUDBURY

Incremental Throughputs & Revenues
RRS Process versus Base Case

PRODUCTS	280 x 10^6 lb/yr Ni		300 x 10^6 lb/yr Ni	
	10^6 lb/yr or 10^3 oz/yr or 10^3 tonnes/yr	10^6 $ US/yr	10^6/lb/yr or 10^3 oz/yr or 10^3 tonnes/yr	10^6 $ US/Yr
Nickel	0	0	0	0
Copper	-7	-6.0	-8	-6.8
Cobalt	+1.82	+8.2	+1.95	+8.8
PM	-6	-1.8	-6	-1.8
Silver	-40	-0.4	-43	-0.5
Sub-Totals		0		**-0.3**
Sulfuric Acid (1)	665	+10.6 to - 8.0	712	+11.4 to - 8.5
(2)	945	+15.1 to -11.3	1010	+16.2 to -12.1
TOTALS (1)	-	**+10.6 to -8.0**	-	**+11.1 to - 8.8**
(2)	-	**+15.1 to -11.3**	-	**+15.9 to -12.4**

(1) Without CCM.
(2) With CCM.

Basis:	$US
Copper:	0.85/lb
Cobalt:	4.50/lb
PMs :	305/oz
Silver:	10^{50}/oz
Acid :	+16/tonne to -12/tonne

TABLE 11

INCO SUDBURY MODERNIZATION ALTERNATIVES - SUMMARY TABLE

THROUGHPUTS	280 x 10^6 lb/yr Nickel				300 x 10^6 lb/yr Nickel			
	Base Case	RRS PROCESS			Hypothetical Base Case	RRS PROCESS		
Ore Milled (10^3 tonnes/yr)	12,100	11,900			13,000	12,700		
Nickel Products (10^6 lb/yr)	280	280			300	300		
Copper Products (10^6 lb/yr)	310	303			332	324		
Cobalt Products (10^6 lb/yr)	3.15	4.97			3.375	5.325		
Pt Group Metals (10^3 oz/yr)	352	346			377	371		
Gold (10^3 oz/yr)								
Silver (10^3 oz/yr)	1,640	1,600			1,757	1,714		
Liquid SO_2 (10^3 tonnes/yr)	100	100			100	100		
H_2SO_4 (10^3 tonnes/yr)								
(without CCM)	0	665			0	712		
(with CCM)	0	945			0	1010		
SO_2 Emissions (10^3 tonnes/yr)								
	770	-			825	-		
(without CCM)	-	318			-	341		
(with CCM)	-	136			-	146		
MODERNIZATION OPTION	Pre 1983	RRS	RRS/IOP	CCM	Pre 1983	RRS	RRS/IOP	CCM
Capital Costs (10^6 $C)	**N/A**	**606.75**	**430.51**	**119.0**	**N/A**	**632.87**	**449.62**	**121.0**
Incremental Revenues (10^6 $US/Yr)	-	+10.6 to -8.0	+10.6 to -8.0	+4.5 to -3.3	-	+11.1 to -8.8	+11.1 to -8.8	+4.7 to -3.6
*Incremental Operating Costs (10^6 $US/Yr)	-	-17.0	-15.6	+3.44	-	-18.0	-16.5	+3.65
Total Incremental Savings for RRS (10^6 $US/Yr)	-	**+27.6 to +9.0**	**+26.2 to +7.6**	**+1.06 to -6.74**	-	**+29.1 to +9.2**	**+27.6 to +7.7**	**+1.05 to -7.25**

* Based on $US=1.25$C